Enriching design with X through tailored additive manufacturing knowledge: a methodological proposal

Laverne Floriane[1] · **Segonds Frédéric**[1] · **D'Antonio Gianluca**[2] · **Le Coq Marc**[1]

Abstract In a few years, Additive Manufacturing (AM) has become a promising technology and opened up new prospects for the product development. Nevertheless, design methods remain predominantly based on conventional manufacturing processes and AM capabilities need to be better mastered and integrated in the design team. This article questions how a new technology (i.e. AM) can enable product innovation. Thus to support designers in preliminary design, a methodology is introduced. The specificity of this methodology is the use of a tailored AM knowledge, i.e. a knowledge delivered to the right user at the right time and in the right format, in order to be useful and usable during the creative stages of the design process.

Keywords Design with X · Design for X · Additive Manufacturing · DWAM · Knowledge · Preliminary design

1 Introduction

Until 1990's, "manufacturing techniques could be classified in two sets, according to the way the product's shape was generated: forming processes and material removal processes" [1]. The industrial era of Additive Manufacturing started in 1986 and enabled to make objects "from 3D model data, layer upon layer, as opposed to conventional manufacturing technologies" [2]. AM brings many changes: tools are no longer needed, products' functionality can be improved, customized and on demand manufacturing is possible. Furthermore, AM now allows the achievement of fully functional products. Thus AM is no longer restricted to rapid prototyping which was until now its main use but also introduces the possibility of rapid manufacturing.

It is also necessary to promote this new technology coming from advances in science and R&D research. Among the three innovation strategies defined by Jaruzelski and Dehoff [3], the techno-push one best fits the current situation of AM: product innovation can arise from an appropriate use of AM and provide new insights into the product development. But facing these new possibilities, it is necessary to provide designers a new set of tools and methods taking into account AM specificities so that AM techno-push strategy is fostered.

The main contribution of this paper is a methodological proposal, based on adequate AM knowledge intakes, which is intended to enhance the use of the innovative potential of AM during the design stages.

2 DFAM in the innovation process

2.1 Definition and classification of the DFAM methodologies

In a highly competitive marketplace, the reduction of time to market, the decrease of the production costs and total quality are major concerns meanwhile the number of product requirements are increasing. To achieve these objectives, interactive design appeared in the eighties in order to join "different engineering cultures by the way of computational tools [or methods and evolved in order to] support the knowledge modelling in preliminary design

✉ Laverne Floriane
floriane.laverne@ensam.eu

1 Laboratoire Conception de Produits et Innovation, Arts et Métiers ParisTech, Paris, France

2 Dipartimento di Ingegneria Gestionale e della Produzione, Politecnico di Torino, Torino, Italy

stages and […] to interactively explore design spaces" [4]. While design has become a team work where all the stakeholders bring and share their knowledge and expert skill, interactive design promotes knowledge assimilation, collaboration between experts and reorganize all the engineering activities around virtual versions of products. Moreover interactive design has become an integrated design because "each participant of the design process has access to a unique data base where the different decisions previously taken are stored in a form of the product model" [5].

Design For X (DFX) methodologies which are the "natural response to improve profitability" [6] combine these approaches of interaction and integration and enable the improvement of the "design product as well as design process from a particular perspective which is represented by X" [7]. DFX also revolutionizes the practice of design because all product lifecycle considerations are taken into account through the introduction of comprehensive knowledge, procedures or metrics. Thus, Design For Additive Manufacturing (DFAM) methodologies are specifically dedicated to the AM paradigm. They are intended to facilitate the consideration of the AM specificities and they provide "an opportunity to rethink [design for manufacturing] to take advantage of the unique capabilities of these technologies" [8]. According to Laverne et al. [9], current DFAM methodologies can be classified according to the product systemic level they are focusing: component level or assembly level.

Component-based DFAM (C-DFAM) methodologies are dedicated to an AM suitable and AM optimized component designed from a given product architecture (or working structure). Firstly, numerical tools are used, such as topological optimization tools or multiphysics simulation ones, in order to take advantage of AM opportunities and thereby develop components with improved performance (e.g. the decrease of the overall mass and volume of a part for unchanged mechanical properties). Furthermore, C-DFAM give a great prominence to the integration of manufacturing constraints related to the limits of AM processes (dimensional accuracy, surface finish, porosity...). Thus, in C-DFAM, the gap between the theoretical model (CAD model) and the actually achieved component is minimized.

Assembly-based DFAM (A-DFAM) are focusing on the product as a whole and are currently far fewer. They are intended to the improvement of a product architecture through the decrease of the components number or to the design of new one. For that, A-DFAM consider different functions gathering into functional sets. From these sets, AM compatible working structures are identified using either CAD model in databases or assessment tools (FMEA, flow-force diagram…) combined with a component design stage.

2.2 Limits of current DFAM methods in an innovative context

Among Von Stamm [10] there is no innovation without design stages. Design process is also the backbone of an innovation process and early design stages, starting from the research of concepts to the delivery of a preliminary layout [11], are the key stages of the innovative design. Furthermore, creativity plays a major role "in the production of novel and useful ideas by an individual or a small group of individual working together" [12] during the preliminary design. Indeed, at this time the designers are working to develop "creative outputs" [13] i.e. design outputs that satisfy two essential criteria for the development of a radical innovation : originality and appropriateness.

Among the various typologies of innovation, the current C-DFAM and A-DFAM are here considered according to their product innovation potential. In these methodologies, the integration of AM Knowledge (AMK) is not used for challenging the specifications obtained during the preliminary studies or for defining new ideas or concepts. Thus their deliverables are mostly redesigned products; that also means an incremental innovation at the assembly level.

In C-DFAM, working structures are not considered. Their components are really different (new shape, new materials …) so that they improve the product performances. However, as Henderson and Clark [14] explain, the sum of component innovation does not lead to a radical innovation for the product since the architectural knowledge (i.e. the "linkages between components and the working structure") is not destroyed. In A-DFAM, the working principle remains unchanged and the working structure evolves in order to fit with the new requirements and constraints such as costs decrease or manufacturing and assembly cycle shortening. It is also a redesigned solution because only some links are destroyed. Moreover, current A-DFAM are less efficient than C-DFAM for the design of individual components and also lead to a poorer adequacy between the "as designed" component and the "as manufactured" one.

These methodologies are also not adequate to produce creative outputs because there is no attempt to find new ideas or concept but rather to adapt or transform them according to the AM possibilities.

However as an architecture is deemed innovative if the concept itself is considered creative and if the arrangement of the different components ensures compliance with the specifications and the technical constraints of the AM and/ or traditional processes, it is therefore essential to develop a methodology that help designers to break free of their architectural knowledge and to think about new concepts that could become creative product architectures.

3 Presentation of the methodology

3.1 Methodological objectives

The methodology presented in the following section, is intended to fill the gap mentioned above through an intake of AM knowledge and suitable to the early design process.

An appropriate methodological response can be based on the improvement of the Design With X (DWX) approach and its linkage with DFAM. Indeed, DWX objective is "to inspire designers and supports them in creating products [because DWX focuses] on innovations so the product design solutions have always an innovative character" [15]. The main use of DWX is Design With User in user centered design because it increases users' involvement compared with Design For Users. Thus, as opposed to DFX_a, DWX_b approaches are not intended to focus the design on a specific purpose X_a but to widen the space solution with special attention to a new item X_b and its characteristics: DWX is also a cumulative approach. In an innovative process, DWX can also assist early design activities and have to be carried out before a DFX method in order to enhance design creativity (Fig. 1).

Since AM opportunities and restrictions are poorly mastered by designers compared with those about traditional processes, we can confirm the interest of a DWX methodology enriched with AM paradigm. We call it Design With AM (DWAM). DWAM will use AM as an extra track to increase the creative potential of designers. But it also involves the introduction of a suitable AM knowledge in order to enable the undermining of the architectural knowledge. Thus, when creative concepts are available, the use of DFAM methodologies is possible to optimize performances and arrangements of the components.

3.2 Importance of AM knowledge for creativity

Among Popadiuk and Choo [16] one of the difference between incremental and radical innovation is the resource and skill requirement: for radical innovation, "additional expertise from outside might be required". Moreover, in their C-K theory, Hatchuel and Weil [17] highlight the importance of a reasoning focused, on the one hand on the knowledge space ("K" space) and, on the other hand, on the concepts space ("C" space) to succeed in an innovative design. The methodology presented in this article is specifically focused on the transition from K to C, called disjunction. It aims to improve the generation of alternative by extending the C space "with elements coming from the space K". These elements are AM knowledge. The relationship between creativity and knowledge has been formalized by several researchers [12,18]; nevertheless, there is no literature available dealing with the best way to introduce AMK to designers.

Laverne, et al. [9] compared the creative potential of design groups with expert or guided AMK (technical briefs and illustrative objects) to an inexperienced group in the AM field. Results showed that a huge intake of AMK is not suitable to ensure simultaneously the development of creative working structures (architectures) and manufacturable components. It seems also more appropriate to split the AMK to make it more understandable and instantly usable. But to achieve this, it requires the identification of the appropriate AMK (i.e. founding adequate content) that designers need for each of their design activities. This tailored AMK depends on three parameters: who, when, how.

- Who is the target i.e. the stakeholder (industrial designer, ergonomist or engineer) or the pluridisciplinary group who will use the AMK.
- When corresponds to the most adequate moment to introduce the AMK.
- How is the best support that embodies and transmits the AMK.

To develop triplets of parameters in line with the content of an AMK, we followed the Grunsdtein's cycle [19] stated for the capitalization of knowledge in companies. This cycle follows four stages: locate, preserve, enhance and maintain.

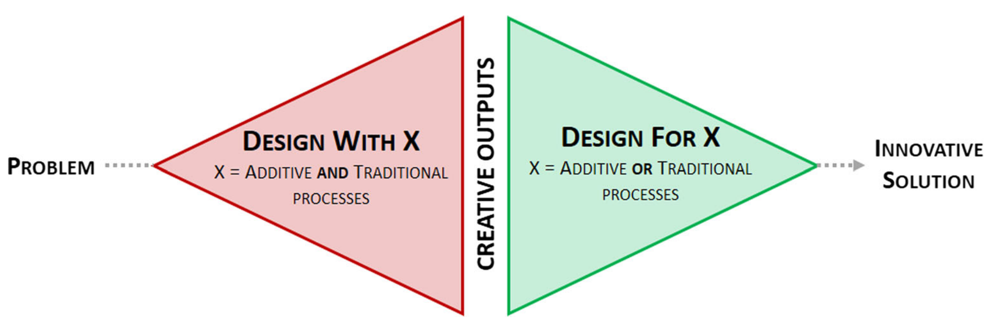

Fig. 1 DWX and DFX in the innovation process

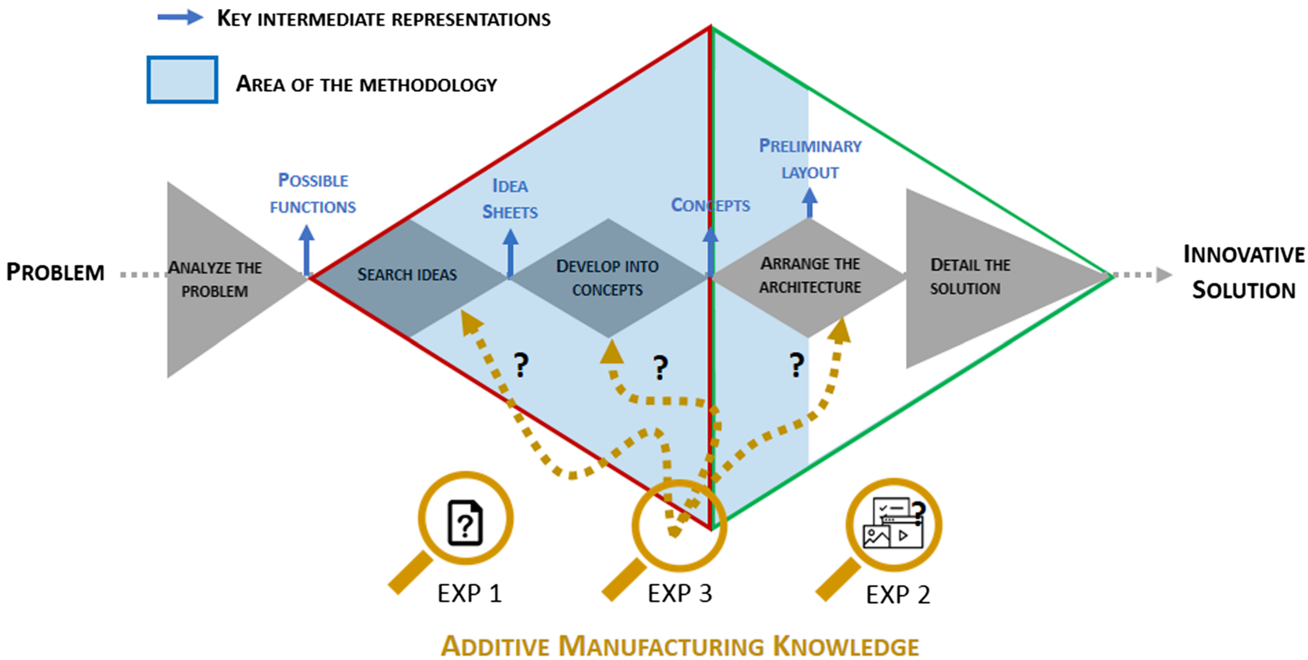

Fig. 2 Initial model and place of experiments

Locate means the identification of crucial AM knowledge (explicit or implicit) for the preliminary design, which refers to the AM content. Preserve involves collecting, modeling and formalizing it from AM experts. The value enhancement are the accessibility and the dissemination of AMK for its use and the "maintain" stage involves the improvement of AMK and its update. These last two steps will condition the choice of a computerized methodological tool because in the current integrated design context all the relevant data are stored and made available for users in the PLM environment [20].

3.3 Initial model of the methodology

To succeed in the development of a methodology based on AMK intake, a preliminary model, adapted from the Pahl and Beitz [21] model of design process is proposed (Fig. 2). This initial methodological model is used as a support for the search of the AMK features (content, timing, target and support) needed to increase the creative potential of designers and consists in five stages.

The first stage of the model is the problem analysis stage. It is an important stage designed to better understand the needs, requirements or constraints of the problem statement although at this stage AMK are not necessary because their contribution cannot impact or improve this analysis.

The two following stages of the model (i.e. search of ideas and concept development) match the conceptual design within the meaning of the Pahl and Beitz. They belong to the DWAM approach, bounded by the left triangle on Fig. 2, because their outputs have to be as creative and original as possible to ensure that the solution is innovative. The AMK contents that must be determined for these stages also have to widen the space solution through a better consideration of the design possibilities and restrictions. The architecture arrangement stage is a part of embodiment design. It focuses on the adequate product configuration that meets the processes constraints. At this stage, according to the selected concepts, AM is either a manufacturing process among others or the only possible one for the product development. The AMK contents are also dedicated to enable DFAM approach, bounded by the right triangle on Fig. 2. The last stage is the detailed design of the solution and is not in the area of our methodology.

Each design stage of the model is divided into two activities (divergent activities which are helpful for the ideation work and convergent ones mainly used for decision making) in order to ease the search of the most suitable moment for a knowledge intake. Moreover, Intermediate Representation (IR), which are product representations created during divergent activities and assessed or ranked according specific criteria during convergent activities, enrich the model. The key IR created during the stages of the model are: the list of possible functions, the ideas sheets, the concepts sketches and the preliminary layout. They serve as triggers for the supply of AMK.

In order to define the tailored AMK needed for each stage of our methodology and based on the model introduced above, three different experimentations are conducted: the first one is dedicated to the determination of the knowledge contents, the second focuses on the suitable knowledge media to convey these contents and the last one focuses on the best timing to bring these contents.

4 Formalization of the “just need” knowledge

4.1 Experimentation 1: knowledge content

4.1.1 Protocol

This experiment is dedicated to the identification of the tailored AMK content i.e. the useful knowledge that fosters the production of creative outputs during each stage of the methodology. It is based on the analysis of the cognitive and informational process followed by 14 designers working on the early stages of innovative industrial project. All participants know AM: its working principles and its main characteristics.

Before the experiment, participants are introduced, during a preliminary meeting, to the framework of the research and the terminology which is thereafter handled is defined. Preliminary design within the meaning of Segonds et al. [11], is located in design and innovation process. Key IR are defined and categorized using Pei’s ID Cards [22]. At the end of the meeting, the participant is asked to select for the upcoming analysis one of the innovation projects he has already achieved in order to provide concrete example.

The experiment is carried out one week after the preliminary meeting and consists in two phases: an interview and a questionnaire.

During the interview, the participant has to describe his current design practices especially on the following topics:

- IR usually created and their illustration with examples from the selected project
- Design activities, design considerations and design stages followed to produce IR or to take decision,
- Inspirational and informational sources,
- Typology of knowledge about traditional or additive processes he handles and applies in his daily work.

Then each participant has to fulfill a questionnaire dealing with the relationship between AM and innovation.

The first part of the survey questions, with a binary scale, the impact of their own AM knowledge on their projects:

- Does it help them found new ideas?
- Which kind of knowledge does they use: restrictive (e.g. knowledge about something that is not possible in AM or that is subject to conditions) or opportunistic one (i.e. knowledge about AM possibilities)?

The second part deals with the product-level characteristics of innovative products defined by Saunders, et al. [23] : functionality, architecture, external interactions, user interactions and costs. The respondents have indicate on a binary scale which characteristics could be improved with a more detailed AM knowledge.

4.1.2 Results

The interviews were used to map design process within the framework of innovative projects. The analysis of these maps shows that there is a shift between the use of knowledge dealing with traditional processes or with AM, especially for projects where regulatory requirements are numerous and rigorous. Indeed in such projects either AMK is not used to think about new solutions, or its use occurs later in the design process, even though the same knowledge content on the traditional processes are already mobilized. The explanation provided by the participants is a “self-censorship” due to the necessary certification process for such kind of products. Indeed the potential benefits offered by AM are attenuated by the fear of a more complicated and longer process which can lengthen time to market. It is therefore necessary to provide AMK in this field to reassure designers particularly during the selection stages.

The analysis of the questionnaire show that although designers say they are aware of the AM working principle and particularly of its usefulness for concepts prototyping, the use of this basic knowledge in a direct manufacturing framework of products is not obvious. Thus, as presented in Fig. 3, 86 % of them answer that a contribution of knowledge dealing with AM opportunities during the early design can be useful and can bring them new ideas. But at the same time, 57 % declare that a knowledge about AM restriction is not helpful during these same stages. These results highlight that designers more easily handle the opportunistic AMK than the restrictive one. It also shows that designers consider that a restrictive AM knowledge has no impact during the creative stages. But while this kind of AMK is really unnecessary

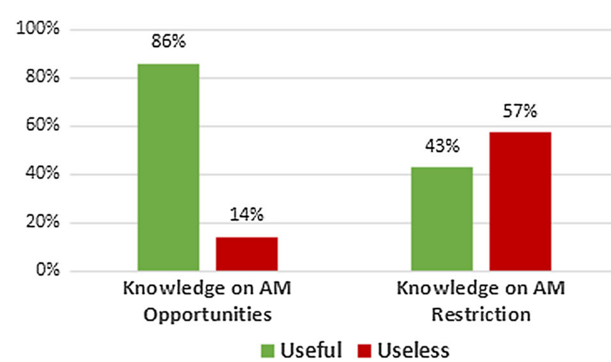

Fig. 3 Evaluation of the usefulness of AMK in early design stages

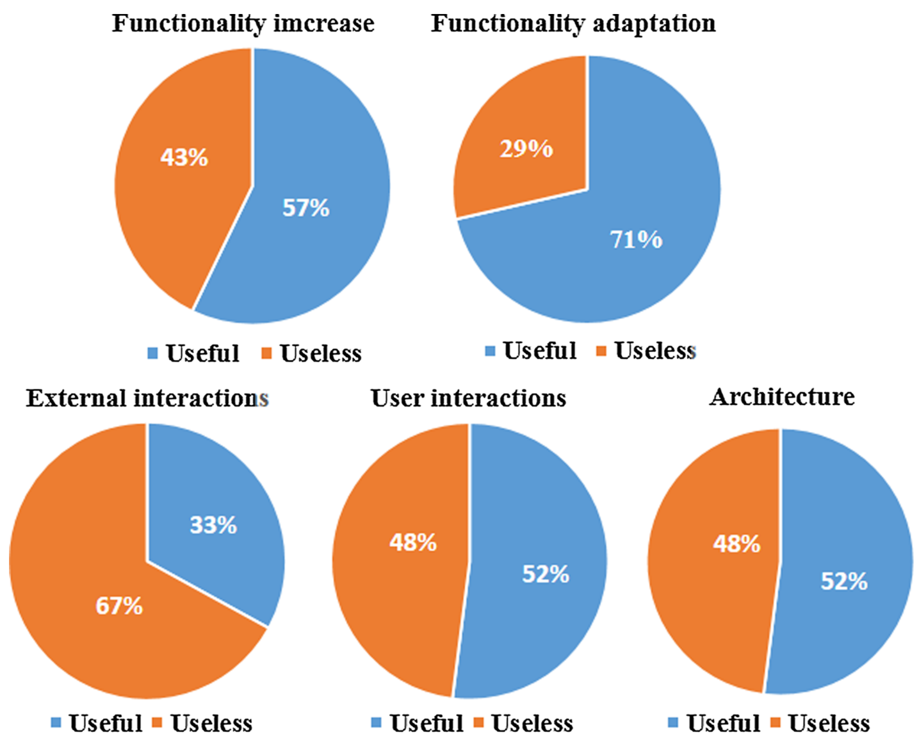

Fig. 4 Perceived usefulness of AMK for the enhancement of innovative characteristics

during ideation (i.e. the first part of each activity of the model), it may nevertheless be required for the converging activities. Indeed it can affect the selection of the creative outputs (functional sets or idea sheets) that will be developed further. It is therefore necessary to bring restrictive AMK during these phases in order to assess IR according to criteria such as certification, development time of the solution…

The analysis of the 2nd part of the survey reveals that specific and targeted AMK are needed. Indeed, although literature shows that AM will facilitate the development of innovative products with at least one of the features stated by Saunders, the analysis of the responses reveals the participants' difficulty in mobilizing their AM knowledge or in the identification of AM opportunities (Fig. 4). Thus, functional innovation appears as the most obvious AM use. However a detailed study of the answers reveals that the AM functional innovation is more a functional change (71 %) rather than a deployment of an additional function in the product (51 %). Architectural, ergonomic or economic innovations seems a prospect for about one in two participants. Finally, innovation coming from the modification of external interactions, i.e. the modification of material, energy or information flows in the product, are only a prospect for 33 % of the designers.

All these findings suggest that the required AMK contents during the preliminary design are linked to the AM unique capabilities set by Gibson et al. [8] and called AM complexities. These AM complexities are categorized in four different families: functional, material, structural and shape. Designers need industrial applications in order to better grasp the scope of these opportunistic knowledge. Several examples are pointed out and described below according to the perceived usefulness of the complexity they are referring:

– Functional complexity: opportunity of adding new function with embedded electronics or sensors, integrated heat exchange and cooling systems…
– Shape complexity: nested forms, bio-inspired forms, with varying thicknesses, apertured…
– Material complexity: multiple materials in a single product, graded materials…
– Structural complexity: lattice or stochastic structures, multi-scale (fractal) structures.

To these four categories of AMK, we add one more item on the potential added value of using AM (lower costs for small series, customization improvement...).

While the main topics of the AMK contents are known, they are not sufficient for designers to improve creative process without considering their support, their delivering time and their target. These topics are the concern of the following experiments.

4.2 Experimentation 2: Knowledge support

4.2.1 Protocol

The purpose of this experiment is to identify the adequate knowledge supports usable in the methodology and more precisely supports that are particularly appreciated by the designers without distinction between the business skills.

The study was conducted on 42 participants (novices and professionals): 21 engineers, 13 industrial designers and 8 ergonomists whose skills are considered as key skills for early product design. The expert skill is the independent variable in the experiment. Each participant had to give his appreciation of the transcription of a same knowledge on different media: text, video, picture and artifact. The assessment is based on functionality, practicality and ease of understanding.

The assessment of each media, which is the experimental dependent variable, is marked on a 5 levels Likert scale where 1 means that the evaluator dislikes it and 5 means that the support is greatly appreciated.

4.2.2 Results

To analyze the results correctly, several statistical tests were performed. Firstly, for each knowledge media, a Shapiro-Wilk W test is used. This test is suitable for small samples size ($N < 50$) and is performed in order to determine whether the distributions in each group (i.e., the distribution of scores for each group of the independent variable) have the same variability and can be considered as normal. The observed distributions inside the three groups were identified as non-normal ($W_{text} = 0.897$; $W_{artifact} = 0.784$; $W_{video} = 0.465$; $W_{picture} = 0.772$ with all with all $W < C(0.05; 42)$ and p-value < 0.05). These results justify the use of a nonparametric test to construe the impact of the expert skills on the appreciation of these knowledge support. A Kruskal–Wallis H test is also carried out to determine if there are statistically significant differences between the three groups of the independent variable (expert skill) on the dependent variable (appreciation score). The test is corrected for ties ranks.

The results of the analysis indicates that there is a significant difference in the medians when the knowledge support is a text. The null hypothesis (no difference between groups) is also rejected at the significant level 0.05 ($H^*_{text} = 12.00 > \chi^2(2, 0.95) = 5.99, p = 2.47 \times 10^{-3}$). The text thus raises mixed opinions within the categories of designers: ergonomists (ER) seem more responsive to this support than engineers (EN) or industrial designers (ID) with $\bar{M}_{ER} = 4.25, \bar{M}_{EN} = 3, \bar{M}_{ID} = 3.08$. For the three other media i.e. artifact, video and picture, there is no significant difference between groups [$H^*_{artifact} = 4.50$; $H^*_{video} = 4.58$; $H^*_{picture} = 5.31$ with all $H^* < \chi^2(2, 0.95)$]. Furthermore, the analysis of the mean scores shows that artifact, video and picture are well appreciated by users ($\bar{M} > 4$) whereas textual support assessment is lower ($\bar{M} = 3.26$) (Fig. 5).

Thus, in order to implement a vehicular knowledge support in the methodology, only supports that get a similar opinion for the 3 expert skills and a good assessment are considered.

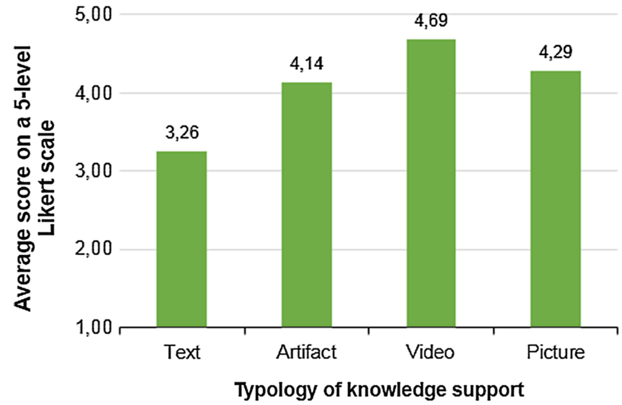

Fig. 5 Appreciation of knowledge support

Yet a need of a regular and quick update of the knowledge contents exclude artifact as a knowledge support, while it is admittedly appreciated. Indeed, the continuous evolutions in the AM field due to the introduction of new processes or materials would involve a frequent renewal of artifacts to maintain AM knowledge updated.

But current PLM tools can't store artefact. It goes against the ongoing concerns on knowledge management and more broadly on integrated design which try to make available all data within the PLM environment in order to improve collaboration: artefact can't be shared in a distributed and asynchronous design environment. Thereby picture-based and video-based media are selected to build the methodological tool.

4.3 Experimentation 3: Knowledge delivery timing

4.3.1 Protocol

The previous experiment highlighted that the choice of a vehicular knowledge support was preferable. This new experiment focuses on the couple knowledge content-timing. Its objective is to identify the best time for the introduction of AMK whose contents were highlighted in Sect. 4.1.2 This just on time AMK delivery means an AMK input suitable to one specific activity of the upstream design process. Thus, bringing AMK prematurely can be hazardous because designers will not use it immediately and may have forgotten it when it will be useful for their job; and bringing it too late is to miss its potential contribution for design.

The study was performed with 18 master degree students mixing engineers, industrial designers and ergonomists. These students are formed in the design and innovation processes and have advanced knowledge in AM. All of them were introduced to the methodological model (design stages and IR). Then the different typologies of AMK (opportunistic and restrictive) are presented and detailed with examples.

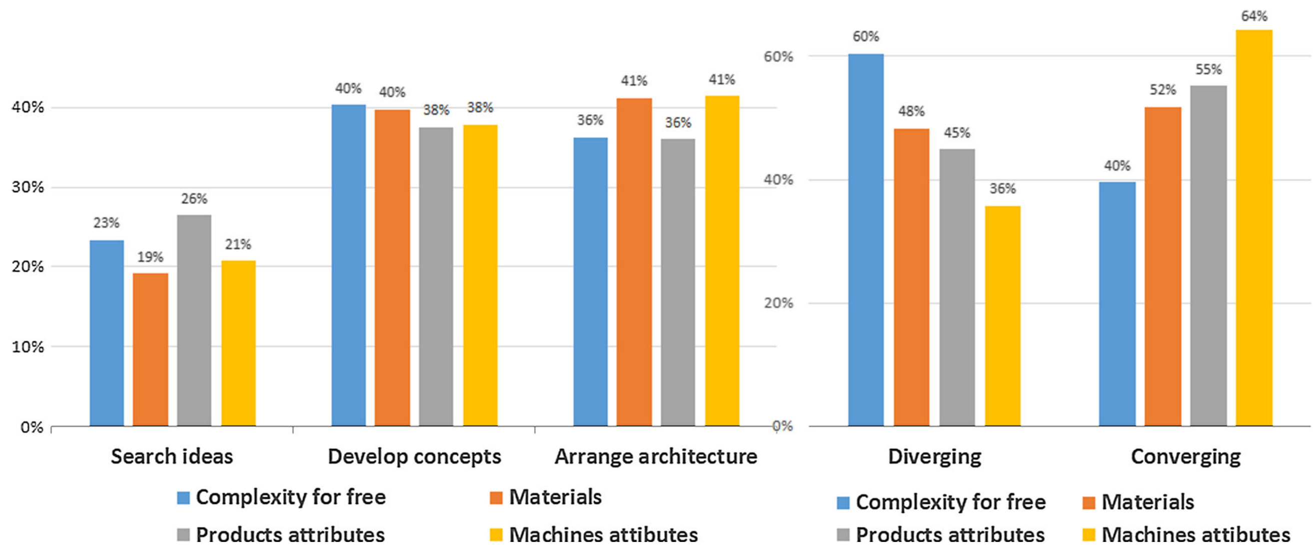

Fig. 6 Distribution of the AMK need time within the stages and activities of the model

Then all the students have to fulfill a questionnaire in which they must specify where, according to themselves, each AMK would be necessary to achieve one or several stages of the model or to perform any of the key IR. It is specified that their choices have to be based on the usefulness and usability that could bring every AMK during their design activities. It is also stipulated that a same knowledge can be handled at several stages of the model.

4.3.2 Results

The analysis of the questionnaire was conducted using quantitative criteria:

- Distribution of the responses in each model stages (search of ideas, concepts development or architecture arrangement).
- Distribution of the responses between divergent and convergent activities.

It appears that the different typologies of AMK are preferentially required from the concept development stage. As shown on Fig. 6 only 1/5 to 1/4 of the respondents (depending on items) consider that some AMK could be used during the search of ideas stage. We can here highlight the misunderstanding of the AMK usefulness during this stage. Indeed, while creativity tools such as TRIZ or brainstorming foster creativity in various fields, without restriction; this misuse can lead to eliminate some viable ideas just because they seem unrealistic with only traditional knowledge. Better knowledge on the attributes of existing AM products (i.e. application areas) or on AM materials and machines (especially about their certifications and qualifications) could prevent the designers' self-censorship.

Knowledge on "complexity for free" is mostly required from the concepts development. Furthermore 60 % of the answers consider that it will facilitate divergent activities. This timing is justified insofar as, during this stage, ideas (functions and working principles) are combined and are then sketched. Such a knowledge is also essential to the creative activities of this stage because it can also help designers to think about new shapes, textures … But 36 % of the respondents consider that it could be useful later (during architecture arrangement), which underlines the significance of an adequate timing.

Knowledge on materials and products seems used both for ideation or selection stages. At last, the intake of knowledge on the characteristics of AM machines is required for concept development arrangement which is quite surprising and inadequate because designers should incorporate the first manufacturing constraints (e.g. dimensional and geometric considerations) in order to shape their concept only during the architecture arrangement.

This experiment also shows that even for participants trained in the design process and theoretically used to mobilize their knowledge at the right time, ignorance of the favorable moments can lead to not benefit of the specific knowledge content to improve a design activity.

5 Proposition of an enriched with AM knowledge model and its integrated tool

The model resulting from the compilation of the experimental studies, defines five specific contributions of AM knowledge,

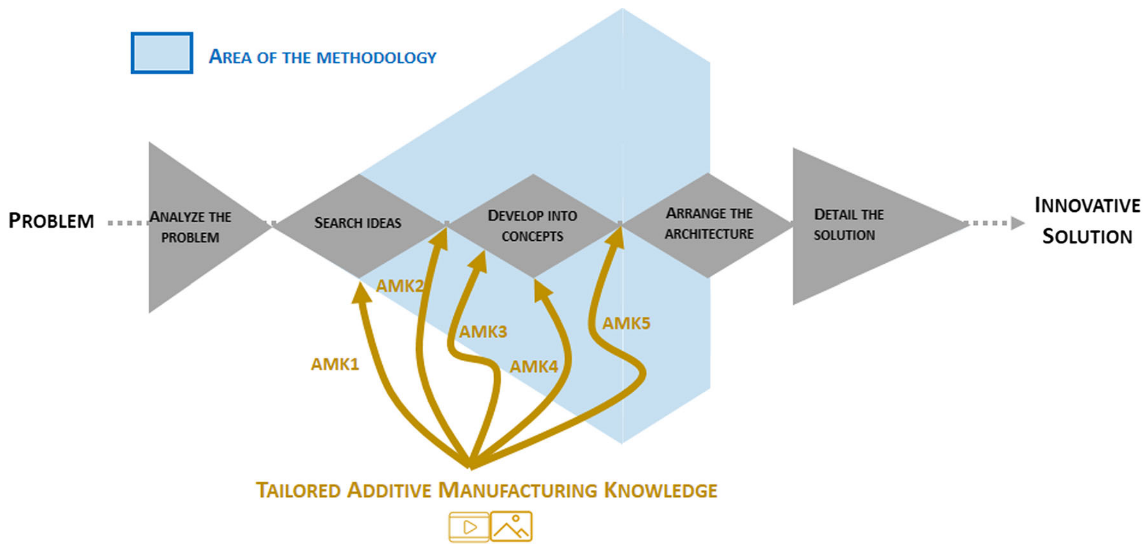

Fig. 7 Final model with AM knowledge

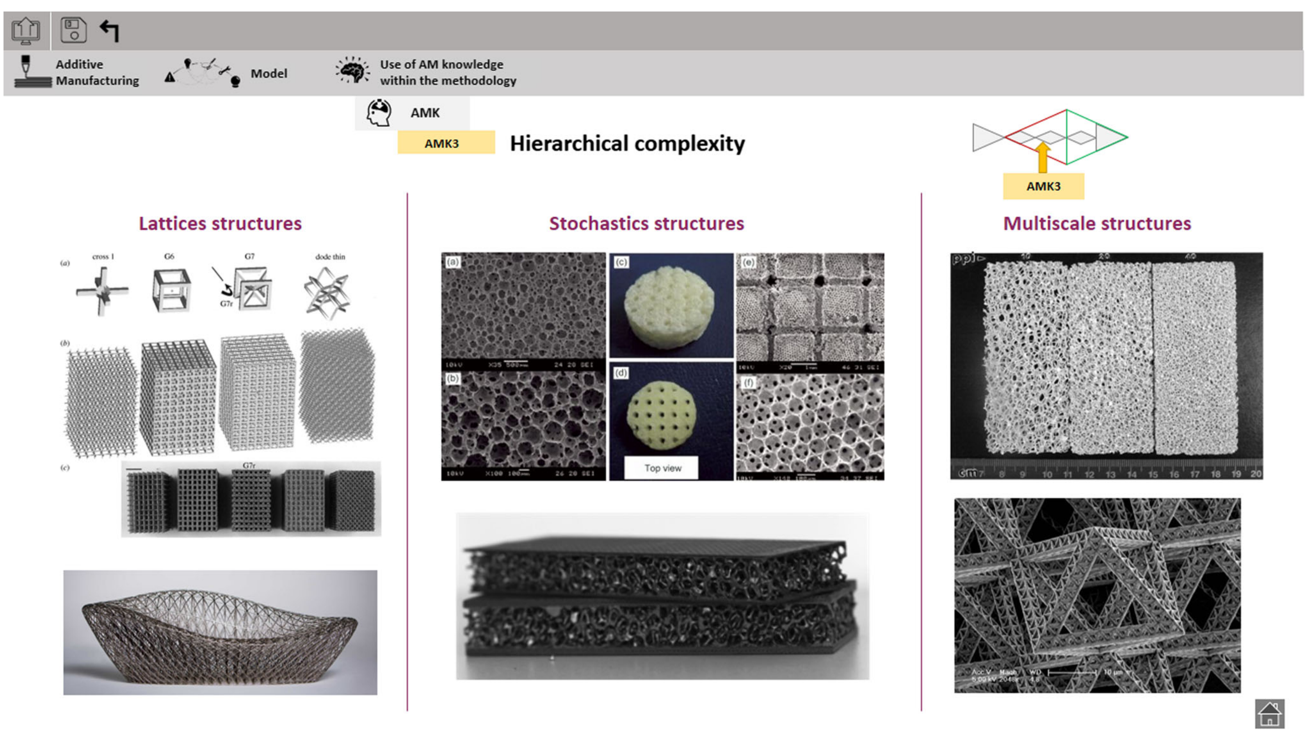

Fig. 8 Support tool snapshot for AMK3 content

during the early design (Fig. 7). Three of them are intended to improve the ideation stages and the two others are dedicated to improve the selection stages.

A demonstration tool (see in Fig. 8) is created jointly with the proposal of the enriched methodological model. This tool is vehicular i.e. is independent from the expert skills of the users. It consists in three menus: AM, methodological model description and AMK for the methodology

- The AM menu is dedicated to introduce AM working principle, definition, machines and products use to a novice user. It uses videos and photos to introduce and explain the contents
- The methodological model description menu defines all the steps, activities and IR handled in the model and illustrates them. Pictures are mainly used to give examples of the key IR.

– The AMK menu has a strong interaction with the model. When a user wants to know if a specific knowledge have to be used to carry out his task, he has to locate in the model the activity he wants to achieve. Once done, he accesses the tailored AMK. Each of them is organized identically. First, user is briefed when the AMK should be considered. This is also a control data which ensures that the user selects the good activity. Then, he is taught wherein AMK may be useful for his work. At last, the AMK is stated and the user can decide to have more details to facilitate its understanding. These clarifications and their appended examples are all based on visual examples as found in experimentation 2. Some short comments are sometimes added to ease the understanding.

Finally, the tool can be used as a learning tool where a user select a specific AMK, read the contents and look when using it.

6 Conclusions and perspectives

This paper presented a design methodology dedicated to a better use of AM knowledge during the early design and is based on "just in time" principles. Experiments enabled the characterization of the appropriate parameters (time, support and content). A tool has been developed to improve the methodological deployment but also to ease the knowledge understanding.

This first model and its associated tool have now to be upgraded and tested both in its content but also in its usefulness for fostering innovation. Thus, assessment of the different AMK is currently started and is based four industrial innovation projects. The collected results will be used to improve the AMK contents but also their associated parameters. The usefulness validation for the delivery of creative outputs have to be performed through a comparative analysis of two workshop carried on several industrial projects. The first one will have to work with our methodology (model and tool), the other will be free to work with method or tool he wants. The comparison will be based on qualitative (expert evaluation of originality, usability…) and quantitative metrics (number of ideas, number of components or functions…).

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